Field-Deployable Acoustic Digital Systems for Noise Measurement

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Langley Research Center (LaRC) has for years been a leader in field acoustic array measurement technique. Two field-deployable digital measurement systems have been developed to support acoustic research programs at LaRC. For several years, LaRC has used the Digital Acoustic Measurement System(DAMS) for measuring the acoustic noise levels from rotorcraft and tiltrotor aircraft. Recently, a second system called Remote Acquisition and Storage System(RASS) was developed and deployed for the first time in the field along with DAMS system for the Community Noise Flight Test using the NASA LaRC-757 aircraft during April, 2000. The test was performed at Airborne Airport in Wilmington, OH to validate predicted noise reduction benefits from alternative operational procedures. The test matrix was composed of various combinations of altitude, cutback power, and aircraft weight. The DAMS digitizes the acoustic inputs at the microphone site and can be located up to 2000 feet from the van which houses the acquisition, storage and analysis equipment. Digitized data from up to 10 microphones is recorded on a Jaz disk and is analyzed post-test by microcomputer system. The RASS digitizes and stores acoustic inputs at the microphone site that can be located up to three miles from the base station and can compose a 3 mile by 3 mile array of microphones. 16-bit digitized data from the microphones is stored on removable Jaz disk and is transferred through a high speed array to a very large high speed permanent storage device. Up to 30 microphones can be utilized in the array. System control and monitoring is accomplished via Radio Frequency (RF) link. This paper will present a detailed description of both systems, along with acoustic data analysis from both systems. A comparison of the performance of the two systems with a detailed discussion on the lessons learned from recent testing will be presented, with a discussion of the advantages and disadvantage of each system, as well future development efforts for both field acoustic array systems.

Introduction

Researchers at the National Aeronautics & Space Administration, are engaged in acoustic research directed towards understanding and reducing noise generated by aerospace vehicles. The research involves numerous field test and measurements of noise signatures from various types of vehicles. Field measurement of noise radiated from flight vehicles provides information not available from wind tunnel tests. In the late 70's and early 80's, field measurements of aircraft noise [1] were used to verify theoretical predictions and to correlate with measurements made in wind tunnels. In the late 80's and early 90's, the increased emphasis on noise reduction technology for helicopters and tiltrotors[2], jet transporter, and future high speed transport placed strong demand for comprehensive field measurement systems. For over a decade, a Digital Acoustic Measurement System developed [3] at NASA Langley Research Center has been successfully used to make acoustic measurements with digitization at the microphones. However, the size of the microphone array is limited by the practical length of cables used to carry the digitized information to the instrument van where the data is stored on

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Abstract

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Jaz drive. The bandwidth of DAMS is restricted because data is multiplexed. The second system called RASS (The Remote Acquisition & Storage System) also developed[4] at NASA Langley eliminates the need for cabling and uses radio frequency (RF) for communication between the RASS and the base station. This paper provides descriptions of each system.

(DAMS) Acoustic Measurement Systems

Figure 1 is a block diagram of the Digital Acoustic Measurement System. The system consists of acquisition and recording systems. The acquisition system has four elements; The remote digitizers located at the microphone digitize the microphone analog outputs, the display and control subsystem, the encoder/decoder subsystem, and the digital acquisition-to-tape interface. Except microphones and remote digitizers, all rest of elements are located in an instrumentation van that can be located up to 2000 feet away. The instrumentation vans are positioned at large distances from the microphones to reduce noise pickup from the van power generators and to avoid interference with the measurement. Digitizing the data at the microphone has allowed a significant increase in the dynamic range(30-40 dB) of the measurement, and this increased dynamic range has all but eliminated the need for operator for gain changes to maintain a good signal-to-noise ratio.

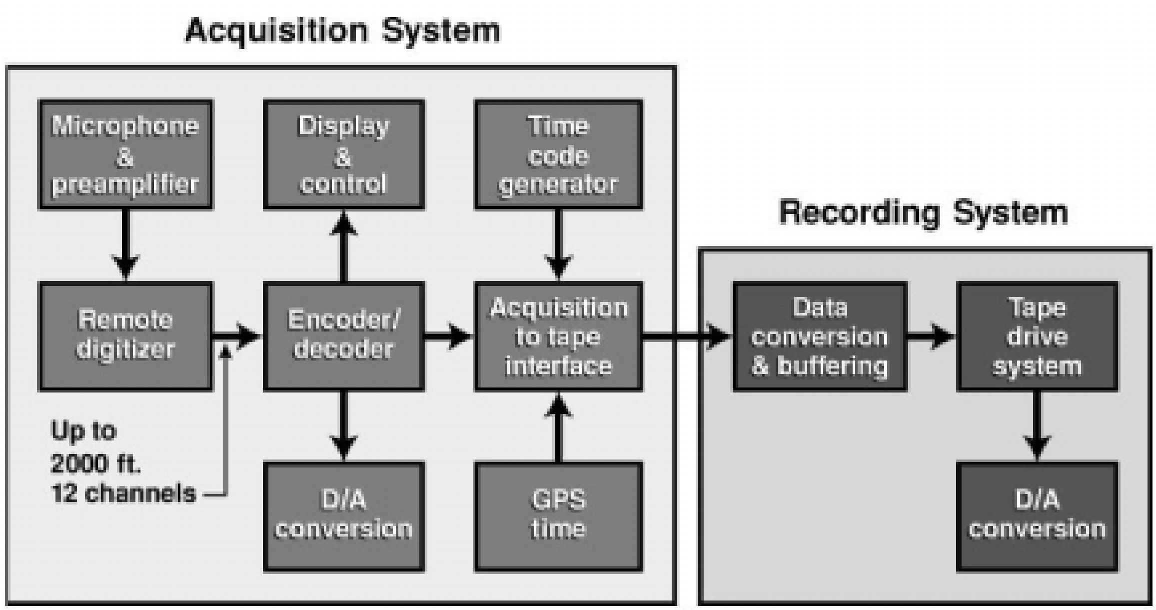


Figure 1: Digital Acoustic Measurement System

Acquisition System:

The acquisition system can be operated in either a synchronous mode or in a non-synchronous mode. In the synchronous mode, sample time is controlled from the instrumentation van; and in the non-synchronous mode, sample time is controlled by circuitry in each remote digitizer. The major elements of the acquisition system are the remote digitizers, the encode/decode subsystem, the display and control subsystem, and the digital-to-analog converter subsystem. Each of elements is discussed briefly as follows:

Remote Digitizer:

The remote digitizer is shown in block diagram form in figure 2. This electronic system is powered by the 6 volts sealed lead acid batteries driving a DC to DC converter, which supplies several voltages to the electronics. The output of the microphone-preamplifier is input to a variable gain amplifier with gains of 1 to 128. The output of the microphone –preamplifier is low-pass filtered and sampled either in a synchronous mode or non-synchronous mode. The sampled analog data is converted to 16-bit digitized data by the analog-to-digital converter. The digital data is then converted to a serial data stream, encoded in a Manchester II code and transmitted to the instrumentation van.

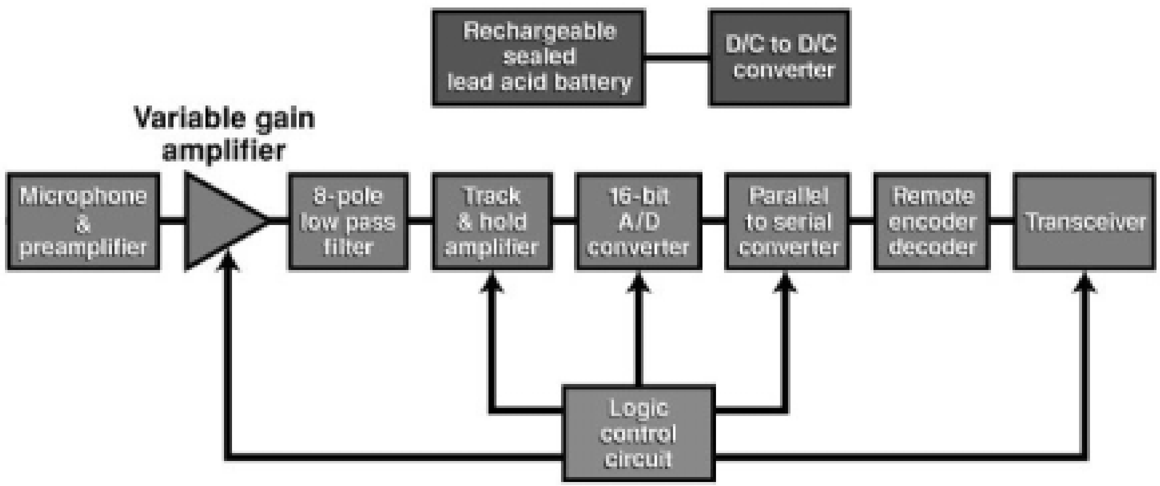


Figure 2: Remote DAMS Digitizer

Encode/Decode System:

It is located in the instrumentation van. In the synchronous data mode, the system encodes the gains to be set on the variable gain amplifier and sends these gains to each remote digitizer, every time it is commanded to sample the microphone data. This system also decodes the Manchester coded data received from each remote digitizer. Full-duplex has been used for communication between the instrumentation van and the remote digitizer.

Display and Control System:

The display and control subsystem is used to display the amplitude of the data from each channel, set the gain of variable gain amplifier in the remote digitizer, detect and alert the operator of overload conditions, and of any faults in the communication of information and data between the instrumentation van and the remote digitizer. The display and control chassis is shown in figure 3.

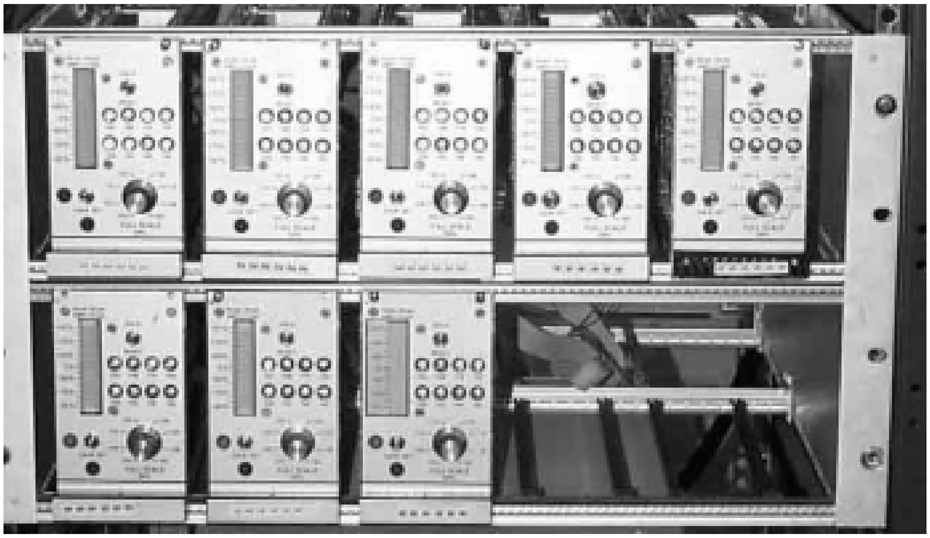


Figure 3: Display and Control Chassis

Digital-to-Analog Conversion System:

Each data channel has a digital-to-analog converter to allow the operator to monitor the data from each microphone. Converting the data to analog at several points in the serial path of the acquisition and recording system allows the operator to isolate system electronic problems to specific elements of the system.

Recording System:

Data from each microphone is filtered, sampled, digitized, and sent to a remote van. The received digitized data is collected and stored on a removable Jaz disk as shown in figure 4 by a Data Acquisition System (DAS). The DAS consists of an embedded National Instrument PC running LabVIEW, and is stored on a removable Jaz disk. For several years, DAMS has been successfully used to make acoustic measurements with digitization at the microphone sites. However, the size of the microphone array is limited by the practical length of cables used to carry the digitized information to the instrument van where the data is stored on Jaz drive. This system served well to acquire field rotorcraft noise data for defining the noise sources, validation of noise prediction algorithms, and evaluation of source noise reduction. However during early 90s, NASA’s noise research had a new challenge. This was the need to evaluate tiltrotor community noise control through flight operations as part of the Short-Haul Civil Tiltrotor Program. With this need, the proven linear array approach was modified to allow noise measurement over a substantially large area under the flight path. The area to be covered is typically 5miles by 5 miles. This area coverage requirement made the usage of cables to connect measuring microphones to the data vans an unattractive option and prompted the development of RASS which uses Radio Frequency (RF) transmission to control and monitor data from microphone locations. Here is description of RASS.

Figure 4: Jaz Drive and DAS

Remote Acquisition and Storage System (RASS)

In addition to DAMS, RASS is another tool for acoustic field testing. The ability of this system to survive in the various field environments is a must. It is essential that the Radio Frequency link be robust enough to allow for communication from the base station to microphone sites. Before deploying the RASS system, optimum placement location of the base and the individual remote sites is determined. Transmission paths from the base station to each remote site are identified with least amount of RF loss possible.

Base Station:

A functional block diagram of base station is shown in figure 5. The major components of the base station are the LabVIEW based user control and monitoring interface, the Pentium based computer with a Serial Line Internet Protocol (SLIP) port, and the Radio Frequency (RF) modem. Control and monitoring interface is critical in allowing the operator to determine if all of the systems are operating properly after initial setup. Figure 6 shows the front panel of the LabVIEW main screen. Specific IP address has been assigned to each of the critical components of the system. On initial power up, the operator would interrogate the controller card for the base station RF modem, and the modem itself, an indication is provided for how long it takes to receive the response back. If the system is not responding to the interrogation, then there is a problem with the RF link between the base station and the remote site. If signal quality is not adequate, the antenna at the remote site will have to be elevated to improve reception. In this way, the operator sends a interrogation to the individual controllers for the remote system to determine proper operation. If a interrogation is not received from a specific controller it is replaced in the field. Once link to all controllers is established, there should be 30 green LED’s at the top of the main LabVIEW screen indicating that all systems are on line and have had no communication errors.

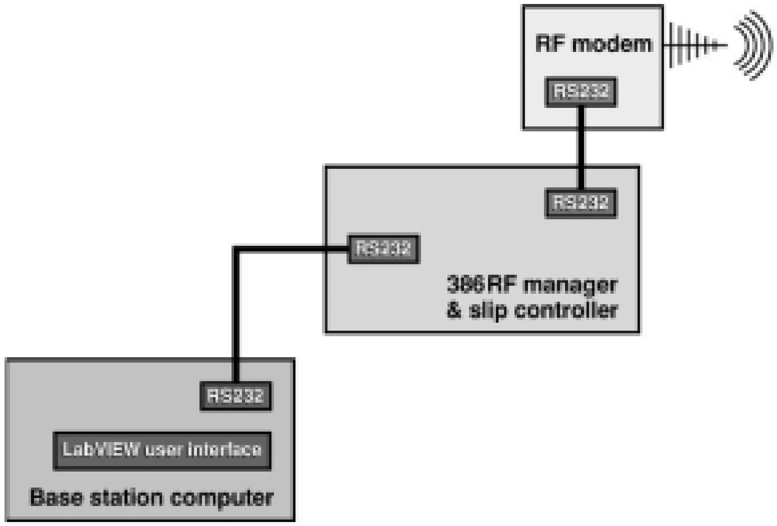


Figure 5: Functional Block diagram of Base Station

During test if command is returned without proper response, green LED turns red. Due to the fact that the data is stored at the remote location, data can not be monitored during a test run. However, after each run the operator can send a read data command to confirm data quality. The data files can be converted into WAV format at the base station. These WAV files can be played using standard sound card, speakers, and software to listen to the data.

Microphone:

The data is taken with an ½ inch Bruel and Kjaer condenser microphone model 4133. The microphone has been a standard in acoustic field measurements for many years and is still one of the best microphone in terms of performance. The analog acoustic signal from the microphone is transmitted over a three foot cable to the remote digitizer box.

Remote Digitizer Box:

This box contains the electronics to digitize the analog signal. The analog signal is input to a digitally controlled anti-aliasing filter. The cutoff frequency of this filter is transmitted over the RF link from the base station and the sample rate is a minimum of 2.5 times filter cutoff. For example, if the cutoff frequency is set to 20KHz, then the sample rate would be at least 50,000 samples per second. A high quality sample and hold, 16-bit analog to digital converter are used to convert the analog signal to digital format. Digitization at the microphone site improves signal to noise ratio, dynamic range, and immunity form Radio Frequency Interference. The digitized data is then transferred to First In First Out (FIFO) buffers which provide speed matching between the data from A/D and the Small Computer Systems Interface (SCSI) storage device. The data is output from the remote digitizer FIFO to the STD bus digital I/O card and is controlled by a 486 processor. The 486 create the header for the data file. This header contains start time of the data file, the file name, run number, and health monitoring information such as internal temperature and capacity remaining on the SCSI storage device.

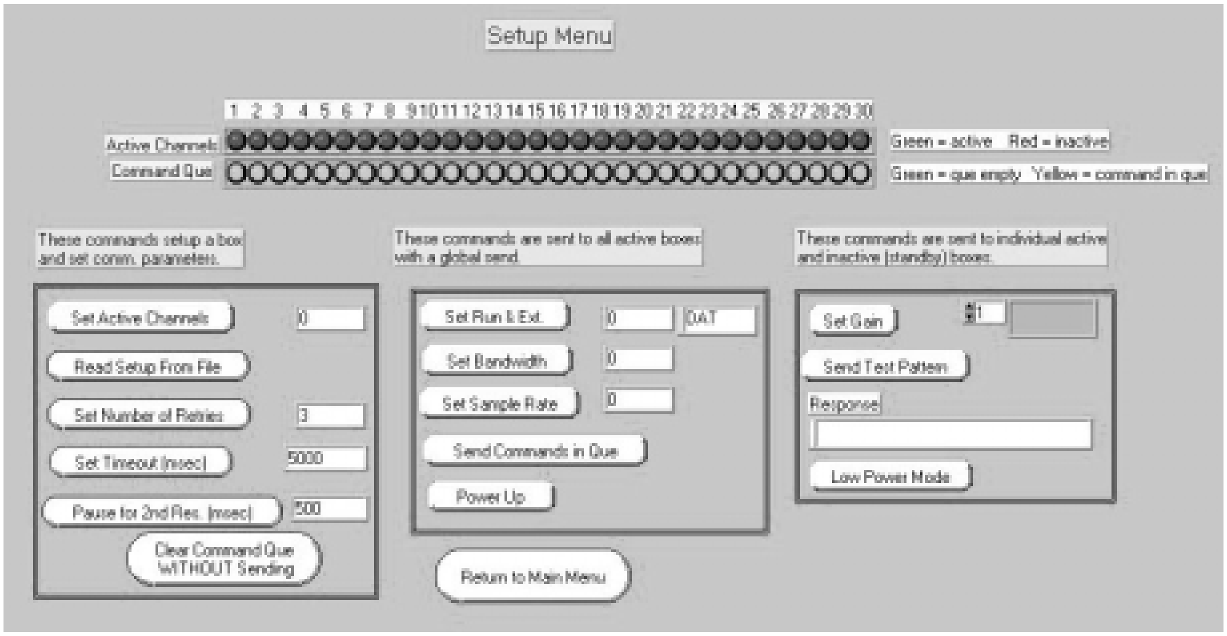


Figure 6: Front Panel of Lab View main Screen

SCSI Storage System:

The data from FIFO to the STD bus digital I/O card is controlled by a 486 processor. This 486 processor is also used to manage the commands from the base station. The 486 processor creates the header for the data file, which contains start time of the data file, the file name, run number, and health monitoring information such as internal temperature and capacity remaining on the SCSI storage device. The 486 also sends the reset to the FIFO's for gathering data and initializes the SCSI card for DMA transfer from the FIFO's to the SCSI storage device.

Meteorological Instrumentation

A tethered weather balloon system and a weather profile system are used to acquire weather information. The tethered weather balloon system consist of an electric winch-controlled tethered, helium filled balloon, an instrument/telemetry pod, a ground-based receiver/data-controller, and a ground-based support computer. Profiles of temperature, relative humidity, wind-speed, and wind direction up to 400-ft. altitude are acquired continuously during each flight test period. The weather profile system consists of a 10-mt. Tower with 10 temperature sensors, 5 anemometers, and three wind direction sensors. The weather profiles are used to obtain detailed weather information near the ground. Weather data for both systems are acquired at a rate of at least six points per minute, displayed in real time, and recorded, along with satellite time code, on a magnetic disk.

Results and Discussion

The following are two examples explaining how these systems (DAMS & RASS) are used for different noise measurements. First is example of XV-15 flight test conducted by a NASA/Army/Bell Helicopter team that addresses tiltrotor noise reduction by flight operations. These tests were conducted in 1997[5,6,7] at a remote test site located near Waxahachie, TX. This test focused on the approach

condition of terminal area operations which was identified as the area of most concern from the XV-15 flight test conducted in 1995. This example explains microphone array setup, signal processing, data repeatability, sound exposure levels for multiple runs at the same flight conditions, approach profiles, and average sound exposure levels. In second example, A-weighted sound pressure level is measured by DAMS microphone 9 and RASS microphone 16. The DAMS microphone 9 was located 20 feet from the RASS microphone 16 to allow comparison of the two systems.

Microphone Array Setup for DAMS (Bell Helicopter Textron Inc. (BHTI) Test):

A large area microphone array was deployed to acquire acoustic data. The array consisted of 30 NASA operated (DAMS), and 7 BHTI operated ground board mounted microphones arranged over a 2000-foot by almost 9000-foot area as shown in figure 7. The center of the hover pad, shown as a black-filled circle, was the origin of the coordinate system used during the test (X = Y = 0). The desired flight track passed directly overhead of the line of microphones located at Y = 0, with the aircraft approaching from the -X direction towards the +X direction. The typical run terminated in an In Ground Effect (IGE) hover over the hover pad. Taking advantage of the symmetry of the acoustic radiation pattern about the XV-15's longitudinal axis, the microphone array was designed to measure the noise directly beneath the vehicle and off to the port side only. For the noise data presented in this paper, the representation of noise to the starboard side is the mirror image of the acoustic data measured off the port side of the vehicle. The large area microphone array is useful for measuring actual ground footprints for any type of tiltrotor flight operations, and is particularly useful for quantification of the acoustic characteristics of a tiltrotor performing highly complex, non-steady state approaches. The shape of this array was designed to capture the roughly teardrop shape of the anticipated noise contours for a tiltrotor performing approaches to the hover pad. The array is widest where the noise levels were anticipated to be the greatest, and the width is reduced with increasing distance from the hover pad.

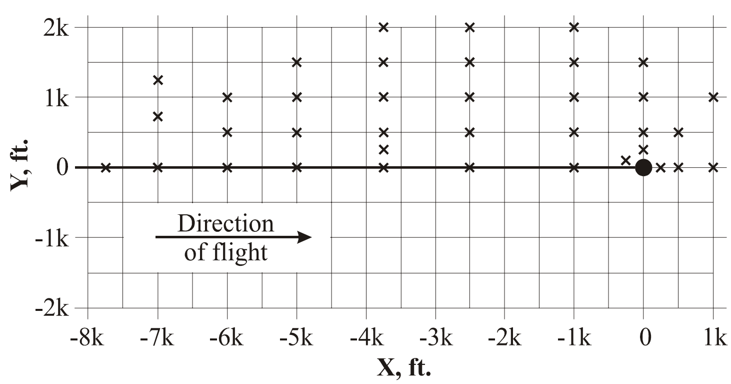


Figure 7. Large area microphone array used.

Signal Processing:

The digital acoustic time domain data sampled at 20 kHz were transformed to the frequency domain using the average of five 4096-point FFTs with a Hamming window and 50% overlap applied. This resulted in 0.6144-second blocks of data for DAMS data. These averaged narrowband spectra were computed beginning every 0.5 seconds for the duration of each run. The average narrowband spectra were then integrated to obtain one-third-octave spectra. The one-third-octave band spectra were then integrated to obtain Overall Sound Pressure Levels (OASPL). In addition, an A-weighting was applied to each one-third-octave spectrum before integration to provide A-weighted Overall Sound Pressure Levels (L_A). These L_A results were then integrated over the time period corresponding to the 10 dB down point from

the maximum level for computation of Sound Exposure Level (SEL). Data plots were generally available the day following acquisition.

Data Repeatability:

As an example of the repeatability of the data acquired during this test, sound exposure levels for the most densely populated line of microphones, located 3750 feet up-range, are presented as a function of the sideline distance for all the housekeeping runs and for all the 6° approaches in figures 8a and 8b, respectively. The figures show that, as one would expect, the maximum sound exposure levels were measured on the flight path centerline and the levels decrease rapidly with increasing sideline distance. For the housekeeping runs of figure 8a, the SEL variation for the centerline microphone and all microphones up to 1000 feet to the sideline are approximately ±0.6 dB or less. The largest SEL variations are approximately ±1.6 dB for the microphones located 1500 and 2000 feet to the sideline. Figure 8b shows that the SEL variations for the 6° approaches was approximately ±2.25 dB or less for all microphones except the farthest out microphone located 2000 feet to the sideline, which had a slightly greater variation of ± 2.75 dB.

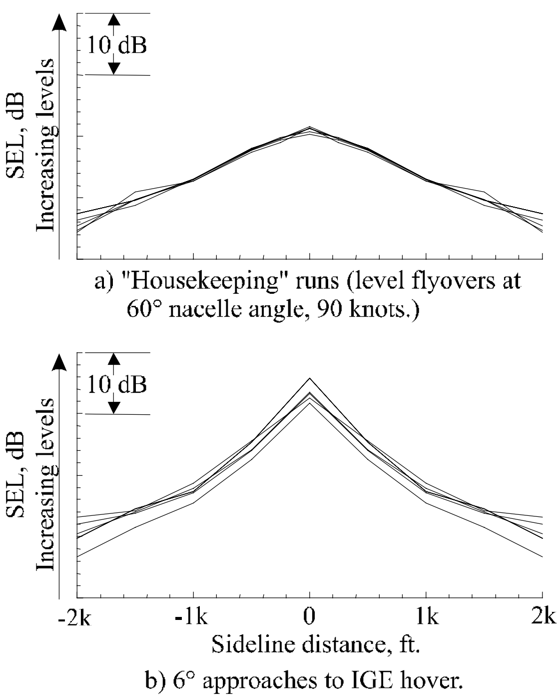
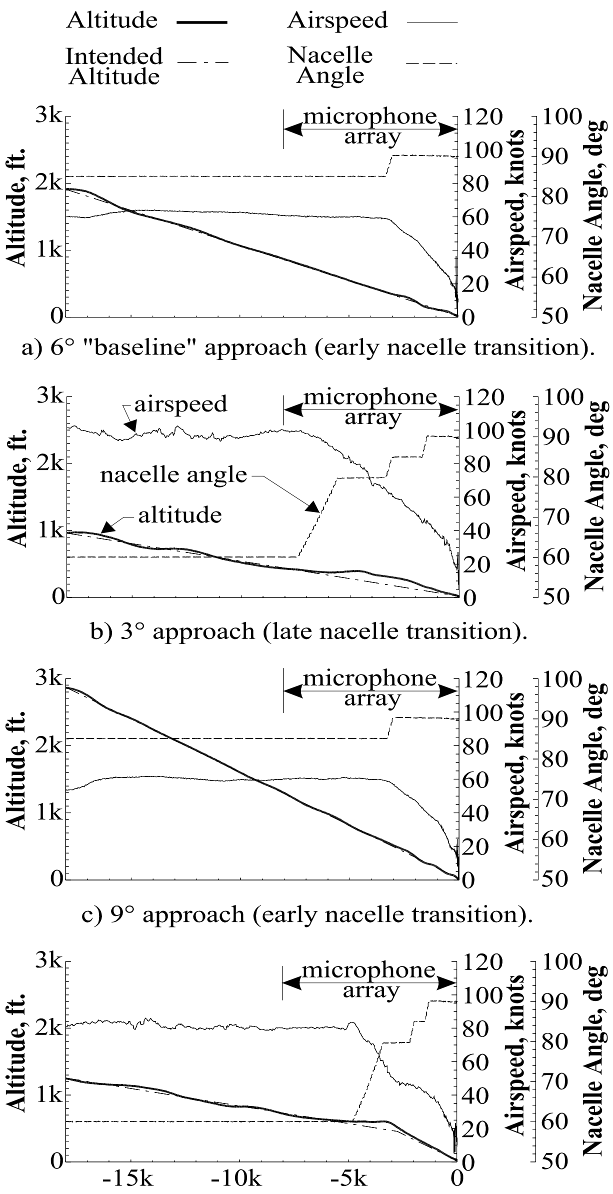


Figure 8. Sound exposure levels for multiple runs at the same flight condition, as measured 3750 feet up-range of the landing point.

Approach Profiles

The primary approach profile parameters for the four selected approaches are shown in figures 9a through 9d. Each part of the figure presents the altitude, airspeed, and nacelle angle as a function of the up-range distance for a single approach. The initial glideslope was intercepted at a distance of 18,000 feet

up-range of the landing point for all approaches. A dash-dot line indicates the intended or desired flight path. It should be noted that while the approach profiles were designed using airspeed, they were flown using ground speed. Prevailing tailwinds of approximately 10 to 15 knots persisted during much of this test, resulting in lower airspeeds than the profiles were designed for.



a) 6° "baseline" approach (early nacelle transition).

b) 3° approach (late nacelle transition).

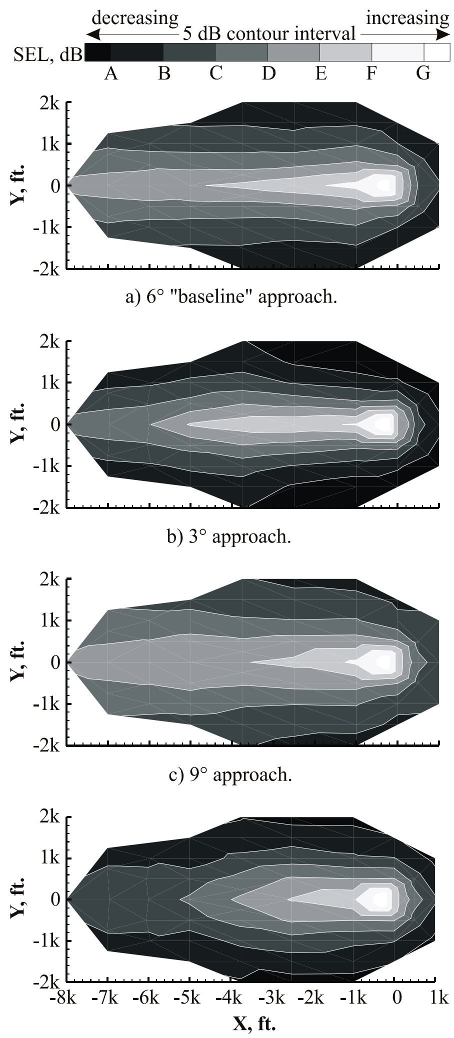
c) 9° approach (early nacelle transition).

d) 3° to 9° segmented approach (late nacelle transition).

Figure 9.   Altitude, airspeed and nacelle angle schedules as measured.

Ground Contours

Figure 10 shows the characteristics of the resulting noise footprints for the same four approaches presented in figure 9. The separation in the contour levels is 5 SEL dB and the contour levels are labeled from A to G with A representing the lowest SEL, shown as black in the figure, and G representing the highest SEL, shown as white in the figure. The contour scales for all parts of the figure represent equal values to allow for direct comparisons. Each footprint extends from 1000 feet down-range to 8000 feet up-range of the landing point and spans up to 2000 feet to either side of the landing point, covering an area of more than 650 acres. The XV-15 approached from the left in the figure, along a line at Y = 0, coming to an IGE hover at about 20 feet AGL over the hover pad located at X = Y = 0. The noise footprints are most useful to provide a qualitative assessment of the noise abatement potential of the different approach profiles. The contour data will be presented in other formats later in this section that will provide for an easier quantitative assessment.



a) 6° "baseline" approach.

b) 3° approach.

c) 9° approach.

d) 3° to 9° approach.

Figure 10. SEL ground contours as measured.

Average Sound Exposure Levels

A more quantitative way to assess the SEL differences for the different approach profiles is to compare the average SEL (AVGSEL) for all microphones, or for a given subset of the microphones. Figure 11a and table 1 identify the different microphone groupings which were averaged and presented here. Figure 11b presents the difference between the average SEL for the 6° approach and the average SEL for each of the other approaches as a function of the microphone group. A negative ΔAVGSEL means that the average SEL has been reduced compared to the 6° baseline approach.

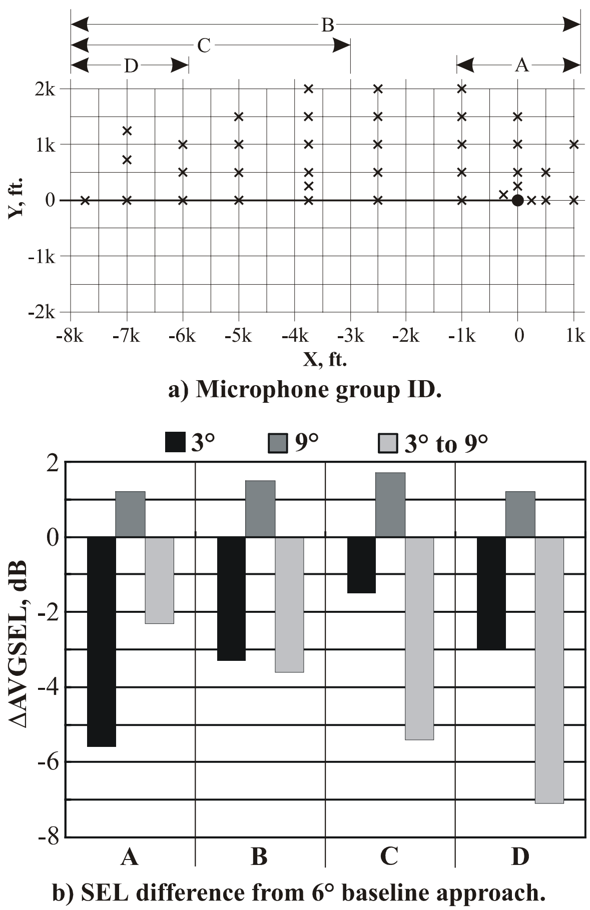


Figure 11. Average SEL differences for selected microphone groupings, as measured.

Contour Areas

Another way to assess the noise abatement potential of the different approach profiles is to compare the ground contour areas exposed to a given noise level. Figure 12 presents the contour area, in percentage of the total measurement area, as a function of the relative SEL for the four different approaches. At the lowest levels, all the approaches converge to 100% of the measurement area, while at the highest levels all approaches eventually converge to 0% of the measurement area. For a given contour level, the largest differences in area between the different approaches are found at the lowest noise levels while the smallest differences are found at the highest noise levels. This figure clearly shows that the 9° approach had the largest contour areas for all but the highest levels. The 3° approach has the smallest areas at the lower levels while the 3° to 9° segmented approach has smallest areas at the higher levels.

Table 1. Microphone grouping ID.

Microphone group ID	Microphones used in average
A	All microphones between 1000 feet down-range and 1000 feet up-range of the landing point
B	All microphones
C	All microphones between 3000 and 8000 feet up-range of the landing point
D	All microphones between 6000 and 8000 feet up-range of the landing point

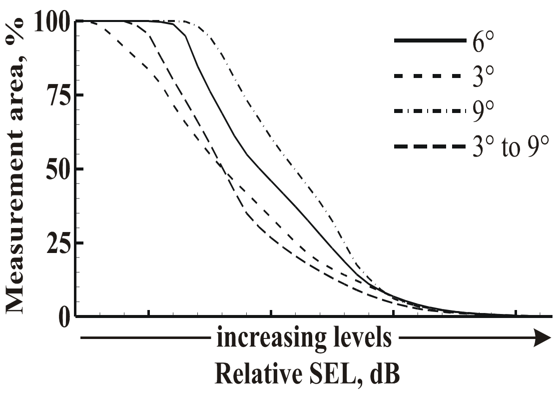


Figure 12. SEL ground contour areas as a percentage of the total measurement area, as measured.

Summary of Noise Abatement Approaches

The 3° approach and the 3° to 9° segmented approach were the quietest approaches tested. This is primarily due to the fact that these approaches maintained a lower 60° nacelle angle until about one mile from the landing point. The combination of nacelle angle, airspeed, and glideslope appear to orient the rotor tip-path-planes to a condition that avoids blade-vortex interactions (BVI). The 3° approach was the quietest around the hover pad, probably due to the lower descent rate requiring less of a decelerating flare to achieve hover at the landing point. The 3° to 9° segmented approach was much quieter at the far up-range distances, probably because the aircraft was on the quieter 3° glideslope but about 300 feet higher in altitude than the 3° approach due to the steeper 9° segment towards the end of the approach. Overall, the 9° approach was the loudest and the 3° approach was the quietest.

Comparison of DAMS and RASS Data

The RASS and DAMS were used for the NASA Langley 757 Community Noise Flight test conducted at the Airborne Express Airport in Wilmington, OH during April 2000. The test goal was to demonstrate and quantify noise reduction benefits achievable though aircraft advanced operational procedures. The NASA Langley 757 would fly conventional and non-conventional takeoff and approach flight configurations over arrays of ground based microphones.

Microphone Array Setup(DAMS and RASS, Wilmington Test):

Two linear microphone arrays were used for the approach and takeoff phase of the test. The takeoff array consisted of 14 DAMS microphones and 6 RASS microphones as shown in figure 13.

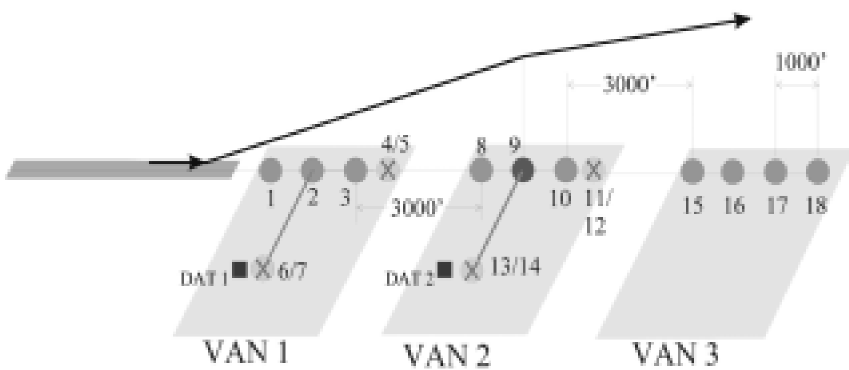


Figure 13: Microphone layout for the departure phase of the test

The array started at 12000 feet from the brake release point on the runway and extended through to 25000 feet. Five RASS systems (6, 7, 23, 13, and 14) were deployed at locations that were not reachable by the DAMS system. Two of the RASS microphones (13, 14) and two of the DAMS microphones (4,5) were deployed 1493 feet to the side of the array to provide lateral attenuation measurements. The RASS microphone 16 was located 20 feet from DAMS microphone 9 to allow comparison of the two systems.

The linear array used for the approach phase of the test consisted of 6 DAMS microphones and 4 DAT microphones as shown in figure 14. The microphones were positioned from 4miles to over 20 miles from the runway.

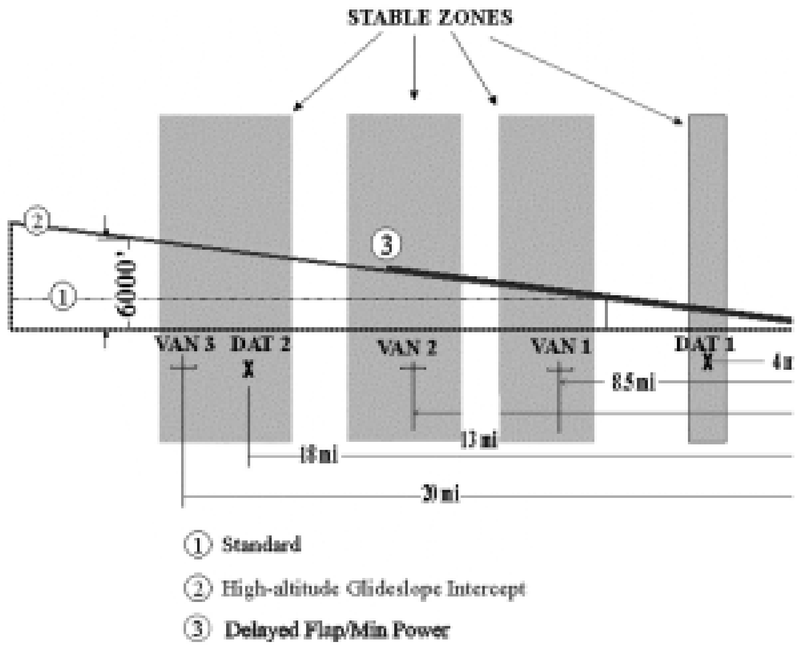


Figure 14. Microphone layout for the approach phase of the test

Signal Processing:

The digital acoustic time domain data sampled at 25 kHz were transformed to the frequency domain using the average of five 4096-point FFTs with a Hamming window and 50% overlap applied. This resulted in 0.4915-second blocks of data for DAMS and RASS data. These averaged narrowband spectra were computed beginning every 0.5 seconds for the duration of each run. The average narrowband spectra were then integrated to obtain one-third-octave spectra. The one-third-octave band spectra were then integrated to obtain Overall Sound Pressure Levels (OASPL). In addition, an A-weighting was applied to each one-third-octave spectrum before integration to provide A-weighted Overall Sound Pressure Levels (L_A). These L_A results were then integrated over the time period corresponding to the 10 dB down point from the maximum level for computation of Sound Exposure Level (SEL). Data plots were generally available the day following acquisition.

RASS Acquisition System Check

The 757 Community Noise Test was the first time the RASS was used in the field for acoustic data acquisition. A RASS microphone (16) was deployed 20 feet from a DAMS microphone (9) located on the centerline array as a means of verifying the RASS data acquisition. Figure 15 shows an example of the measured A-weighted Sound Pressure Level for a DAMS microphone and a RASS microphone from a departure flight run. The figure shows both systems measuring the same ambient levels as the aircraft approaches the microphones. The levels increase as the aircraft appears overhead and the fall off as aircraft flies past. The figure shows excellent agreement between the RASS and DAMS acquisition systems.

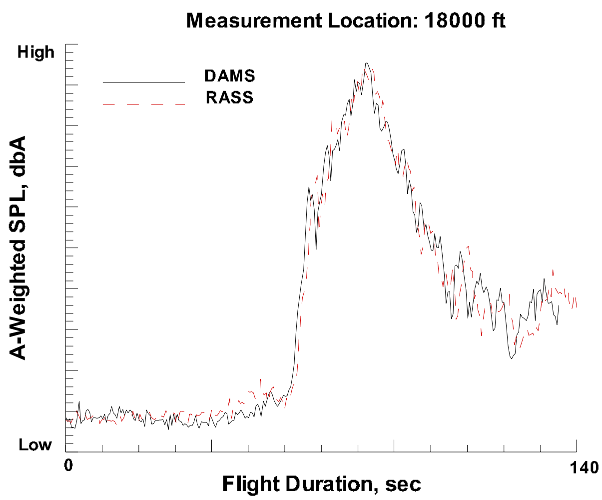


Figure 15. A-weighted Sound Pressure Level as measured by DAMS microphone 9 and RASS microphone 16.

Data Repeatability

As an example of the repeatability of the data acquired during this test, sound exposure levels, SEL, for the baseline procedure from both the departure and approach flights are shown in figure 16 and 17 respectively. Figure 16 shows the SEL for two repeat runs for the baseline departure condition where the 757 takeoffs at a nominal takeoff de-rate thrust until the aircraft reaches an altitude of 1500 feet. At this altitude the thrust is cutback to a maximum climb thrust setting for the duration of the run. The thrust cutback occurred at approximately 15000 feet from brake release that coincides with the peak SEL value shown in the figure. The figure shows excellent repeatability between the two runs.

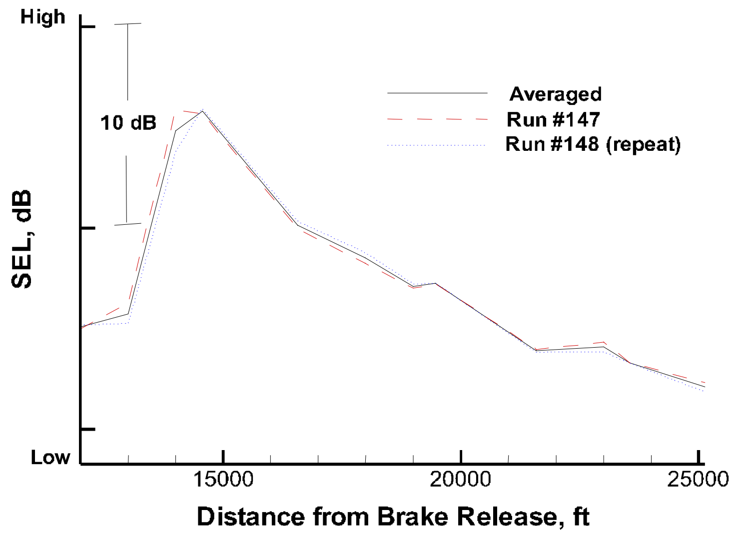


Figure 16. Sound exposure levels for two runs at same baseline departure flight conditions

The measured SEL for repeat runs of the baseline approach procedure is shown in figure 16. The baseline approach procedure uses the standard approach pattern and nominal speed/flap schedule. Again the figure shows consistent repeatability between the repeat runs.

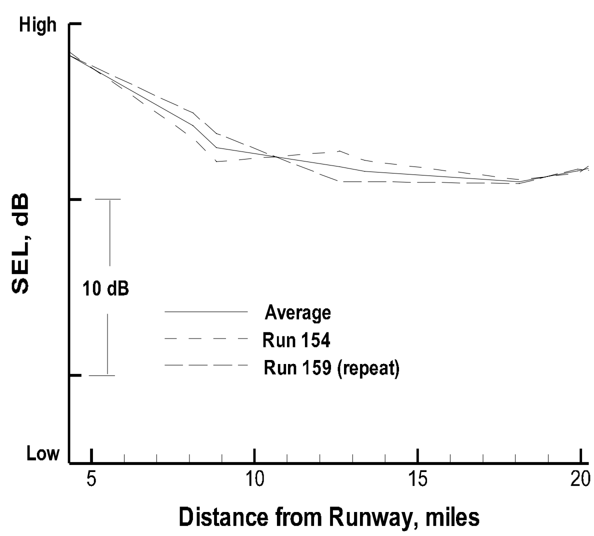


Figure 17. Sound exposure levels for two runs at same baseline approach flight conditions

Future Efforts

An emerging micro-machining technology coupled with the latest cutting edge technologies for smaller, faster, and more accurate systems have opened the way for upgrading and enhancing capabilities of DAMS and RASS. These emerging technologies enable advances such as real-time display, real-time analysis, higher wireless transmission rates, simultaneous data analysis for multiple users and data processing at the base station which is not possible with the existing systems. All these capabilities are being incorporated which will make these systems as state-of-the-art.

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